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COMPARING THE APPLICABILITY OF WEIGHT-LENGTH RELATIONSHIPS, THE RELATIVE CONDITION INDEX AND MORPHOMETRIC CRITERIA TO ASSESS LARVAL CONDITION: A TEST CASE WITH STRIPED BASS

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ABSTRACT: We compared the applicability of using a weight-length relationship, the relative condition index (Kn) and morphometric criteria to provide insight on the nutritional condition and recruitment potential of larvae of the striped bass *Morone saxatilis* collected in the Potomac River, MD in 1980-1982 and 1986. Morphometric data indicate that relatively high numbers of larvae in poor condition were present in samples taken prior to mid-May in all years except 1986, but especially in 1980 and 1981. Results of ANCOVA on a subset of data from the first 2 weeks of May in each of the 4 years indicated significant differences in weight-length regression equations. Larvae in the 1980 and 1981 samples were in poorer condition than in 1982 and 1986, based on regressions coefficients. Estimates of relative condition (Kn) were high in all years except 1986. The morphometric criteria and the regression parameter estimates concurred with an index of striped bass year class strength, but only after a careful consideration of the assumptions of those condition indices, requiring a reduction in sample size that excluded larger larvae (> 12 mm, morphometric criteria) or averaging data over several larval cohorts (regression parameters).

The analysis of condition based on ratios of weight to length is widely used in fisheries science. Various indices typically measure either the condition of individual fish or populations as condition factors (a) expressed in the form:

$$a = \frac{\text{Weight (W)}}{\text{Length (L)}^b}$$

Recently, both Cone (1989) and Bolger and Connolly (1989) reviewed the applicability of weight-length ratios, but they arrived at contradictory conclusions. Cone (1989) suggested that the three commonly used condition indices, Fultons condition factor ($K = W/L^3$) relative condition ($Kn = W/L^b$) and relative weight ($Wr = W/W^s \times 100$), depend upon assumptions that are difficult to meet and that estimation of least-squares regression parameters in the form $\log_e (W) = \log_e (a) + b \log_e (L)$ is a more accurate method to examine condition via the weight-length relationships of fish populations. He further concluded that an appropriate condition index or measure should be employed only after a detailed examination of both the underlying assumptions of the index and the properties of the data set is made.

In contrast, Bolger and Connolly (1989) concluded that using regression parameter estimates from weight-length relationships is inappropriate to analyze fish condition because of the difficulty in interpreting results. Both the slope and the intercept of the regression equations must be evaluated and heterogeneity in regression coefficients or intercepts is problematic. They suggested that larger slopes are indicative of better condition only if the intercepts on the ordinate are the same. Weight-length regression lines that cross one another may be especially misleading (Bolger and Connolly 1989). They follow Ricker's (1973, 1975) admonition that geometric mean (GM) regression is the correct way to calculate weight-length regressions, but then face the dilemma of the lack of suitable statistical tests for comparison of GM regressions. Moreover, Cone's original treatment (1989) has inspired some contention about which of the weight-length ratios or indices are statistically sound (Springer and Murphy 1990; Gutreuter 1990; Cone 1990) or most appropriate and/or useful (Anderson 1990; Miranda and Jackson 1990). Such debate makes it difficult to decide which of the techniques is utilitarian and applicable to field data.

In this study, we compared the applicability of using weight-length relationships, the relative condition index (Kn) and morphometric criteria as a measure of larval condition in an extensive data set — larvae of striped bass, *Morone saxatilis*, collected over a 4-year period in the Potomac River, Maryland, a major spawning area in Chesapeake Bay. Fultons conditon factor (K) and relative weight (Wr) were not included in this analysis because of the difficulties in meeting the assumptions of isometric growth ($b = 3.0$) for Fultons K and because Wr is a variation of the regional definition of Kn (Gutreuter 1990).

Although the senior author previously had examined the condition of larval striped bass from the Potomac River in 1981 and 1982 using histological, morphometric and biochemical techniques (Setzler-Hamilton et al. 1987), we undertook this study with no preconceived notion of whether the applications of length-weight or morphometric techniques were descriptive or comparable. Instead, we wished to examine the utility of these various relationships to analyze a large data set. We ask the following questions. Does the data meet required assumptions for the validity of analysis results? Can these analyses be applied to fragile fish larvae which are easily damaged by capture in plankton nets? Do results of the analyses provide insights into the recruitment process?

METHODS

Sampling methodology for 1980-1982 and 1986 was similar and has been described by Martin and Setzler-Hamilton (1981), Setzler-Hamilton et al. (1981), and Martin et al. (1985). To eliminate the effects of size, e.g., length in the analysis, only feeding-stage striped bass larvae between 5 and 8 mm notochord length (NL) (i.e., the size likely to be starving, $N = 554$) were used. We first assessed the nutritional state of larvae used in this study by morphometric criteria. A suite of six measurements (to the nearest 0.1 mm); notochord length, horizontal eye diameter, head length, head depth at the rear margin of the orbit, body depth at pectoral fin, and body depth at anus, was obtained with an ocular micrometer in a dissecting microscope from at least 30 randomly chosen larvae per sample. Measurements were incorporated into an allometric index that includes all possible ratios of linear measurements (Martin and Malloy 1980). Larvae were classified by stepwise discriminant function analysis (Theilacker 1978) into "starved" or "fed" categories based on morphometry of larvae in labortory experiments (Martin et al. 1985; Martin and Wright 1987). Scores for field-caught

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larvae are reported as the percentage of each sample that sorted into the starved morphometry category.

The larvae then were dried at 60°C for one week and weighed to the nearest 1.0 μg with a Cahn electrobalance. Kn or relative condition was estimated as the ratio of dry weight (mg) to length (mm) raised to a power from some population growing under standard conditions (Ricker 1975). We used 4.0 as the standard regression coefficient based on our pooled data and literature (Eldridge et al. 1981; Houde and Lubbers 1986; Tuncer 1988; Chesney 1989; Monteleone and Houde 1990).

Weight-notochord length regression relationships were expressed as $\mathrm{Log_e W}$ (mg dry weight) $= \mathrm{Log_e a} + \mathrm{b\ Log_e L}$ (mm NL). Differences in the larva weight-length relationships between years were examined using a heterogeneity-of-slopes model in analysis of covariance (ANCOVA); the Scheffe F-test ($\alpha = 0.05$) was used to determine the equality of slopes (SAS Inst., Inc. 1985).

Difference in weight-length relationships of fish have been attributed to season (Cada et al. 1987) and location (Hile 1936). Striped bass larvae used in this study were collected during late spring in 1980, 1981, 1982 and 1986 in a 64 km stretch of the Potomac River, MD. Thus, differences in these relationships attributable to location were minimized. To reduce effects of sampling over several larval cohorts (i.e., season), the analyses also were run on a subset of data comprised of larvae collected during the first 2 weeks of May in each of the 4 years.

We compared the measures of condition to an index of recruitment of Potomac River juvenile striped bass. This index, the average catch of young-of-the-year striped bass per seine haul in major striped bass spawning areas in the Maryland portion of the Chesapeake Bay and its tidal tributaries, has been measured since 1954. It is the only juvenile index of Atlantic anadromous stocks which is significantly correlated with subsequent commercial landings (Schaefer 1972; Austin and Hickey 1978; Florence 1980; Polgar 1980; Cohen et al. 1983; Goodyear 1985). Juvenile seining indices for the Potomac River for the period 1980-1986 are listed below:

Year	Potomac Index(PJI)
1980	2.3
1981	1.4
1982	10.0
1986	9.9

The mean index in the Potomac River, MD for the years 1954-1989 is 6.3 (SE = 1.2; N = 35) (ASMFC 1989). Below average recruitment occurred in 1980 and 1981; above average recruitment occurred in 1982 and 1986.

The nutritional state of larvae used in this study was compared to a previous histological study (1981, 1982) of the nutritional state of striped bass larvae from the Potomac River (Table 1; Setzler-Hamilton et al. 1987). Morphometric and biochemical criteria also were used to ascertain nutritional state in the earlier study. Pertinent results from these morphometric and histological analyses are discussed.

RESULTS

The size of striped bass larvae at time of collection during April - early June varied annually in the Potomac River estuary. In general, more large larvae were present after mid-May in 1982 and 1986 than in 1980 and 1981 (Figure 1). Separation between year groups (1980-81 vs. 1982-86) was evident by the third week of May.

More than 40% of the striped bass larvae used in the analyses from collections in 1980 and 14% of those collected in 1982 were classified as starving based

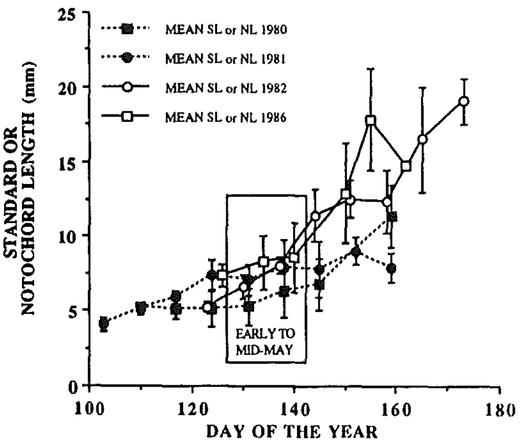

Figure 1. Mean length of striped bass larvae from the Potomac Estuary, 1980-1982 and 1986. Vertical bar gives 1 standard error.

on morphometric criteria (Table 1). High numbers of starving larvae were present during the first 2 weeks of May in 1980-81, but especially in 1980. Few larvae were classified as starving in 1982 and 1986.

Analysis of covariance (ANCOVA) showed significant differences ($P < 0.01$) in weight-length relationships in the whole data set (April - early June collection period; N = 554) for the 4 years examined (Table 2A & B). Estimates of regression coefficients (b) ranged from 3.97 to 5.44. Regression slopes for years 1980 and 1982 were similar and higher (Figure 2A) than for 1981 and 1986 (Scheffe F-test, $P < 0.05$). ANCOVA results from the data subset (first 2 weeks of May, N = 341) also indicate significant differences in estimates of slope and intercepts ($P < 0.01$) in the weight-length regression equations (Table 2C & D). The slope parameters in 1980 and 1981 were significantly lower ($P < 0.05$) than in 1982 and 1986 (Figure 2D).

For the whole data set, Kn ranged from 8.8 to 16.8 (Table 3). Values of Kn were high (14.0 - 17.8) in 1980 - 1982 and lowest in 1986. For the data subset, Kn similarly indicated that larvae collected during the first two weeks of May in 1986 were in poorer condition (less plump) than in the other three years (Table 3).

DISCUSSION

Result of this and a previous study (Table 1; Setzler-Hamilton et al. 1987) indicate that 5-8 mm NL striped bass larvae from the Potomac River were in "poor" condition throughout April and May in 1980 and 1981 and in "good" condition in 1982 and 1986 as evidenced by both morphometric (all years) and histological (1981 and 1982) criteria. The morphometric criteria agree favorably with the PJI (Table 4) when recruitment was above average in 1982 and 1986 and below average in 1980 and 1981. Likewise, in their previous study, Setzler-Hamilton et al. (1987) reported that the percentage of striped bass larvae that sorted into the "starved" category based on morphometry of larvae in 1981, 1982 and 1985 was strongly inversley correlated to the PJI. However, larvae captured in their samples after mid-May were larger (up to 25 mm SL) and the morphometric criteria, when used to evaluate condition of these larger larvae, was useful only to distinguish between the "poor" year 1981 and the other "better" years. This result occurred because few large larvae are

Table 1. Summary of results of a discriminate analysis of striped bass nutritional condition based on morphometric criteria (Morph.). Values indicate the percentage of larvae in a Potomac River sample that sorted into the "starved" category. Also given are data from Setzler-Hamilton et al. (1987) showing the percentage of larvae in samples collected in 1981-1982 that were in poor nutritional conditon based on histological (Hist.) scores < 14. The whole data set represents larvae collected from April to early-June each year. ND = no data.

	Whole Data Set		First Half of May	
Year	Hist. (%<14)*	Morph. (% starved)	Hist. (%<14)*	Morph. (% starved)
1980	ND	43.2%	ND	38.5%
1981	54.6%	13.9%	70.1%	22.9%
1982	22.0%	5.6%	42.5%	6.5%
1986	ND	5.0%	ND	4.5%

*From Setzler-Hamilton et al. (1987)

Table 2. Analysis of covariance results and regression parameter estimates which summarize the relationship between mg dry weight and notochord length in mm of striped bass larvae collected in the Potomac River, MD in 1980-1982, and 1986.

A. Whole Data Set (April-June Collection Period)

Dependent variable: Log_e Weight $r^2 = 0.63$

Source	DF	Sum of squares	P>F
Model	1	215.741	0.01
Log_e Length (slope = 0)	1	146.277	0.01
Year Group (same intercepts)	3	1.911	0.06
Log_e Length/Year Group (same slope)	3	2.342	0.03
Error	547	145.135	
Corrected Total	554	396.876	

B. Whole Data set (April-June Collection Period)

Year	N	b(SE)	$log_e a$	r^2	NL(SE)
1980	127	5.44 (0.63)	-11.63	0.37	5.74 (0.63)
1981	191	4.27 (0.25)	- 9.56	0.73	6.56 (0.87)
1982	159	5.07 (0.25)	-10.87	0.72	6.38 (0.88)
1986	77	3.97 (0.32)	-9.41	0.62	6.38 (0.73)

C. First 2 Weeks of May

Dependent variable: Log_e Weight $r^2 = 0.66$

Source	DF	Sum of squares	P>F
Model	7	109.194	0.01
Log_e Length (slope = 0)	1	35.442	0.01
Year Group (same intercepts)	3	2.537	0.01
Log_e Length/Year Group (same slope)	3	2.837	0.01
Error	334	56.366	
Corrected Total	341	165.560	

D. First 2 Weeks of May

Year	N	b(SE)	$log_e a$	r^2	NL(SE)
1980	61	2.43 (0.82)	- 6.52	0.34	5.54 (0.44)
1981	84	3.24 (0.39)	- 7.67	0.58	6.58 (0.69)
1982	130	4.73 (0.29)	-10.30	0.67	6.21 (0.86)
1986	66	4.06 (0.38)	-9.63	0.62	6.34 (0.69)

likely to be starving and the morphometric score is correlated to length when larvae are > 12 mm SL (Martin and Wright 1987).

When all data were considered, estimates of regression parameters (slopes) from ANCOVA also did not vary in accordance with the PJI, a result of averaging over multiple cohorts of larvae, including those collected in late May when no starving larvae were present in any samples. This result was not unexpected, however, because during any extended sampling period weight-length relationships and ratios reflect the average condition of larvae in the sample. Growth rates of striped bass larvae vary widely both between cohorts, and between individual larvae in the same cohort. Cohort-specific growth rates of striped bass larvae from the Potomac River in 1987 averaged 0.29 mm d^{-1}, but ranged from 0.18 to 0.43 mm d^{-1} (Houde et al. 1990). In general, larval cohorts collected in late May were growing faster than cohorts collected earlier in the spawning season (Houde et al. 1990).

Although our data are insufficient to

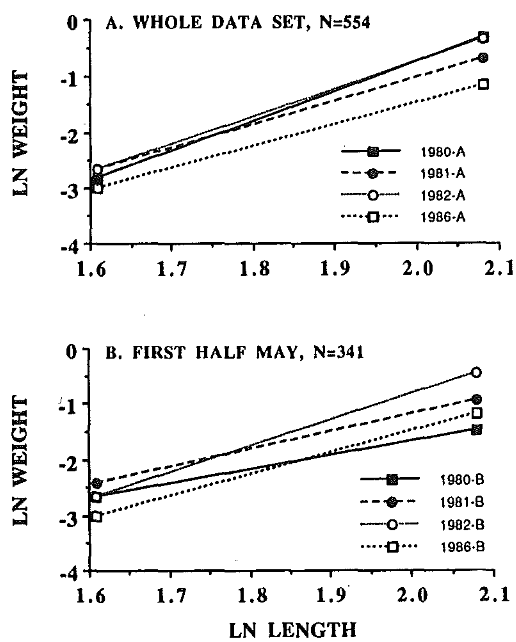

Figure 2. Plot of linear regression relationships between weight and length of striped bass larvae in the Potomac River, MD in 1980-1982 and 1986. The whole data set is comprised of larvae collected from April-early June each year. Regression parameter estimates were generated using Analysis of Covariance.

distinguish between larval cohorts, interpretation of regression parameters from ANCOVA results from larvae collected during the first 2 weeks of May suggests that larvae collected in 1982 and 1986 were increasing in form (i.e., higher slope; Cone 1990) faster than larvae collected in 1980 and 1981 (Figure 2). These data also indicate, however, that larvae collected in 1982 and 1986 did not always have higher weight at length than larvae collected in the other years (Figure 2). If we assume that the form of the weight-length regression relationship is the best estimation of nutritional history (following Cone 1989, 1990), the early May regression slopes agree with the PJI (Table 4). ANCOVA results also indicate that the data for years 1980 and 1981 should be pooled to produce ($P < 0.01$; $r^2 = 0.57$):

$$\log_e W = -8.63 + 3.72 \pm 0.27 (\log_e L)$$

which may represent a better estimate of the weight-length relationsihp for 5-8 mm NL striped bass larvae when growth in length is slow compared to the equation derived from the pooled 1982 and 1986 data ($P < 0.01$; $r^2 = 0.66$):

$$\log_e W = -9.84 + 4.38 \pm 0.28 (\log_e L)$$

when growth in length is more rapid.

The low r^2 in the weight-length relationships (Table 2) suggests that the length measurements may have been problematic. Small larvae are fragile and accurate NL measurements on curled or bent larvae from archived samples are difficult without video imagery. The lowest r^2 value (0.37) occurred in 1980, a year when the mean length of larvae was smallest of the 4 years studied (Table 2). Undoubtedly, the lack of precision in measurements adversely affects the sensitivity of the morphometric and condition indices.

For the whole data set (N = 554) and the May data subset (N = 341), the measure of relative condition (Kn) did not concur with the morphometric and regression parameter data and, hence, the PJI. Moreover, assumptions of this condition index are difficult to meet. Because the estimated regression slopes were not equal, strict interpretation of Kn is invalid (Gutreuter 1990). Futhermore, the measure was an antipodal function of the slope (form) of the regression equations

Table 3. Estimates of relative condition (Kn) of striped bass larvae collected in the Potomac River, MD in 1980-1982 and 1986. The whole data set represents larvae collected from April-early June each year.

	X 10^5	
	Whole Data Set	First Half of May
Year	Kn	Kn
1980	16.8	11.5
1981	14.0	12.1
1982	17.8	14.7
1986	8.8	8.4

Table 4. Results of the condition indices relative to the mean Potomac River juvenile index (i.e., in 1980 and 1981 the index was below average and in 1982 and 1986, above). Above/below in the other columns indicates our interpretation of significant trends in the estimates of each index value relative to their means.

		Whole data set (April - June)			First 2 Weeks of May		
Year	Juvenile Index	Morphometric criteria	Regression slope	Kn	Morphometric criteria	Regression slope	Kn
1980	below	below	above	above	below	below	below
1981	below	below	below	below	below	below	above
1982	above	above	above	above	above	above	above
1986	above	above	below	below	above	above	below

(i.e., the intercepts were high when the slopes were low). Consequently, it appears not to be as useful an index of conditon or summary of weight-length relationships for these fish larvae because of the dependence on a common slope and one that is dependent on some estimate of the slope from a population growing under standard conditions (Le Cren 1951 cited in Cone 1989, 1990).

Despite our attempt to meet assumptions or reduce the problems associated with averaging over several age/size, location, or seasonal strata, all of the measures of condition appear to be sensitive, to some degree, to violations of these assumptions and may not detect between year differences in conditon unless the indices are carefully employed. Further subsetting (e.g., by mm size-classes) of the data may have proven useful to improve the performance of the measures, but the statistical power lost due to lower sample size, fewer degrees of freedom and lack-of-fit (i.e., lower r^2) can make detection of real differences improbable.

We conclude that the morphometric criteria and regression parameter estimates were more sensitive to apparent between-year differences in condition of striped bass larvae from the Potomac River estuary than was the measure of relative condition (Kn). However, we believe that the relationship between larval growth, condition and recruitment is subtle and difficult to measure. Relatively small variations in growth or mortality rates can result in orders of magnitude variation in recruitment (Houde 1986, 1987, 1989). Although these various indices can distinguish gross differences, the sensitivity of indices to subtle changes in conditon may not be good and larval condition ultimately may not equate with recruitment potential unless mortality is strongly size dependent (Cowan and Houde 1992; Cowan et al. 1992).

We also assume that the Maryland index (PJI) for juvenile striped bass is the best criterion by which to judge the performance of the condition indices. Although this index can be used to monitor relative recruitment of the striped bass population, it is not precise. Heimbuch et al. (1983) statistically analyzed the index and concluded that because of patchiness of juveniles within a river system, only very good and very poor years can be distinguished from average years with confidence.

Peak spawning of striped bass in the Potomac River usually occurs from the latter half of April through the first week of May (Setzler-Hamilton et al. 1981). If we assume that the probability of survival of striped bass larvae primarily depends upon events that occur in the first three weeks of life (Uphoff 1989), then typically the greatest variability in vital rates of larvae in the Potomac River would occur prior to mid-May. Consequently, differences in condition indices that may reflect measurements of larval characteristics that affect recruitment should be most evident during that time period. Under such circumstances as illustrated in this example, i.e., a carefully subsetted data set from a critical time period, measures of condition employing fish larvae can be useful. However, given the observed problems with each measure of conditon used in this study, Cone's (1989) recommendation that an appropriate measure be selected only after a detailed examination of both the underlying assumptions of the index and the properties of the data set is well founded and should be heeded.

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